# High $T_c$ Superconducting Offshore Wind Turbine Generators – An Introduction


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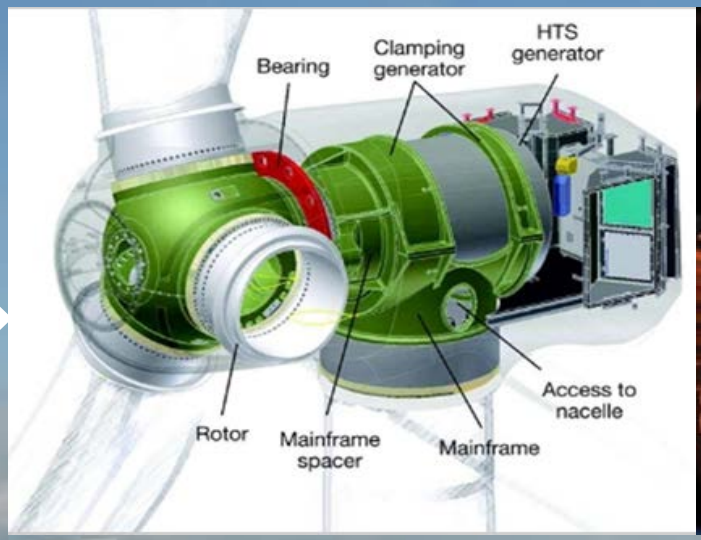
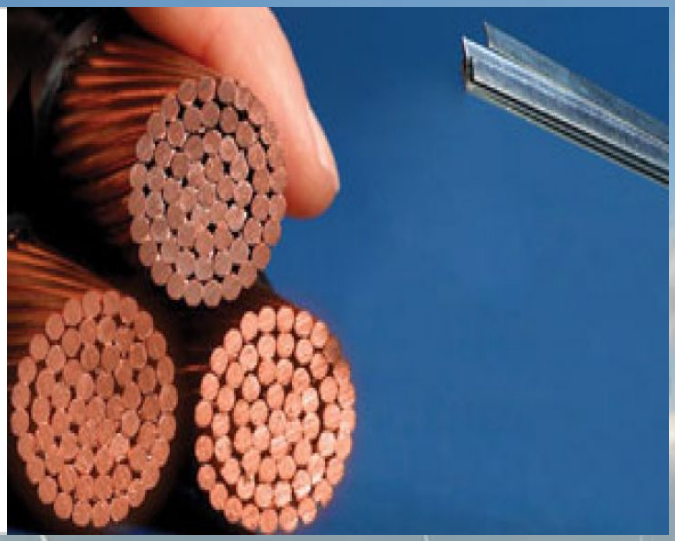
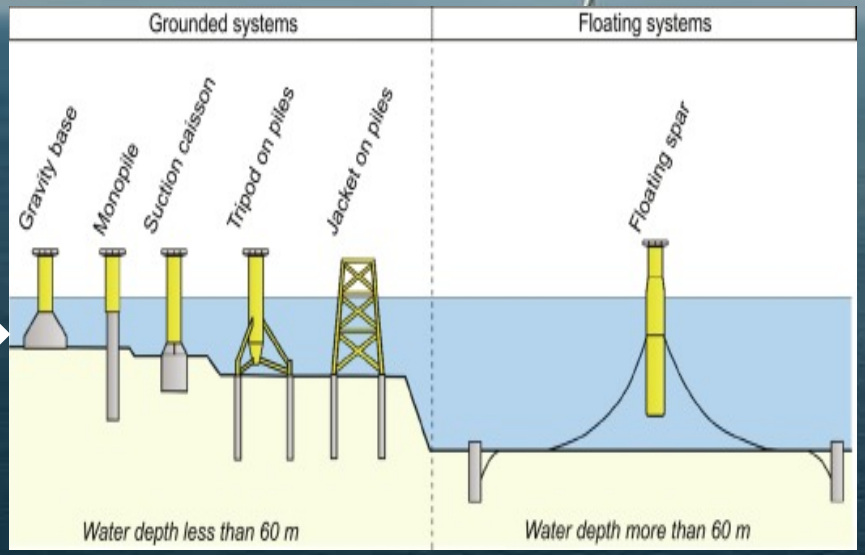





**Top 5 offshore markets in 2018 : China – 1800MW; United Kingdom – 1312MW; Germany – 969 MW; Belgium – 309 MW; Denmark – 61MW**

# INTRODUCTION

- Intense efforts are going on to realize HTS based offshore located wind generators-array, supplying free unlimited power without burning any fuel, making it environmentally friendly.
- As more and more longer lengths of HTS tapes are made available, it will drive the offshore wind industry with its green credentials to have an excellent business case to venture into creating large wind farms based on HTS wind turbine generators.

Fig A - Generator that uses HTS tapes

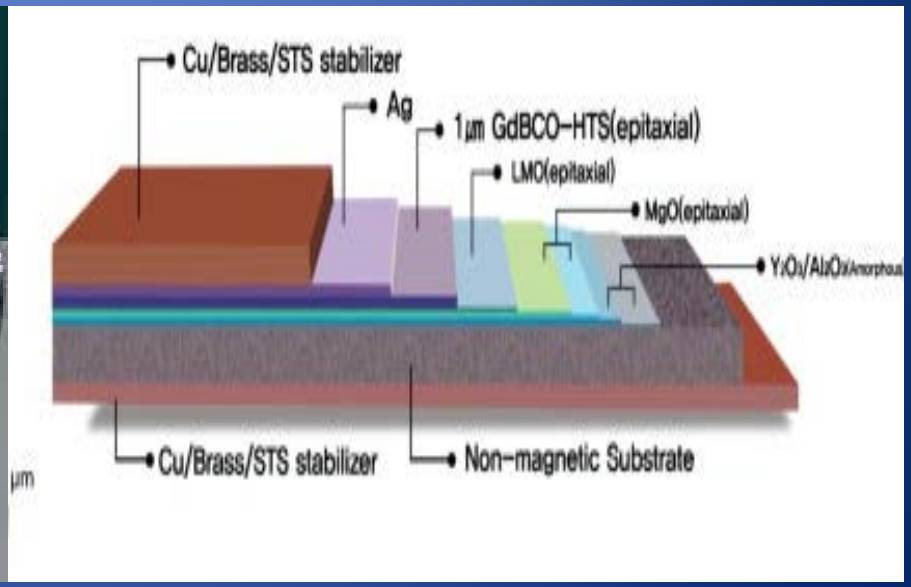



Fig B - 2G HTS TAPE

# INTRODUCTION

- HTS based generator is lighter compared to its copper counterpart as it does not require iron poles in view of the fact that the high fields (more than 2T) anyway saturates the iron thereby making it as air core.
- In addition, it is easy to obtain permission on offshore compared to getting permission to use vast land onshore.
- Further, the wind conditions are more favourable on offshore compared to onshore, to realize more MW per year for each installed MW unit offshore.

# ADVANTAGES

- The tower size and complexity of a wind turbine can be reduced by using lightweight/compact HTS machines.
- Due to the use of lightweight components, it becomes easy to build and transport large machines(>10MW) with complete assembly to the installation site.
- The use of gearbox can be eliminated by enabling direct coupling to the wind turbine
- The efficiency will be more when compared to conventional machines.
- HTS machines can produce more torque when compared to conventional machines.

# CHALLENGES

- Cooling the HTS rotor field coils to 50K along with its vacuum insulation under rotation, with the shaft coupled to wind turbine, using suitable cryo-refrigerators of 1kW rating at 50K.
- Cost of long length HTS tape-production to be reduced drastically (few $/kA-m) to compete with copper conductors with necessary superconducting/ mechanical properties.
- Reduction of AC losses and increase of current densities at higher fields (>2T) of long length HTS tapes. Suitable power electronics with energy storage elements such as SMES to be developed onshore to couple the fluctuating power output of offshore HTS based wind turbine generator to the national power grid demanding continuous, controlled quality power with constant voltage/frequency.
- Strong floating platforms made by advanced composite materials, arranged in 2-D array on sea to support the wind turbines along with HTS generators and control circuits.

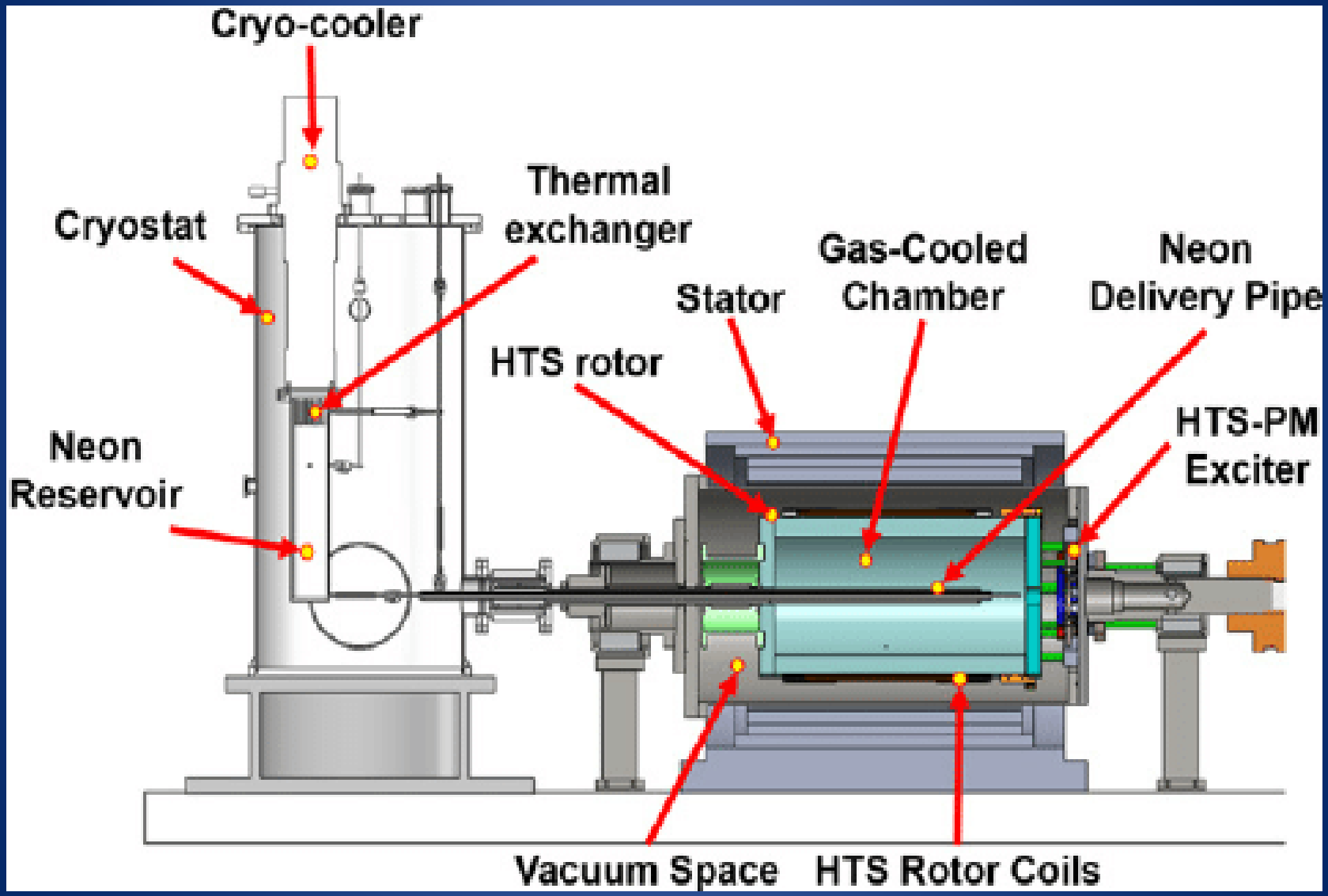
# IMPORTANT POINTS ABOUT OFFSHORE WIND TURBINE

- The typical output voltage of a wind turbine is about 690 volts, AC.
- Offshore wind farms use undersea cables to transmit electricity to the grid.
- A slender tower stretches 100m above the waves.
- At wind speeds 36–54 kph (10–15 m/s), maximum power can be generated.
- Innovative floating offshore wind platforms are under development for use in deep water. Three kinds of floating platforms are spar-buoy, tension leg platform, and semi-submersible.
- Offshore winds are typically stronger during the day, allowing for a more stable and efficient production of energy when consumer demand is at its peak.

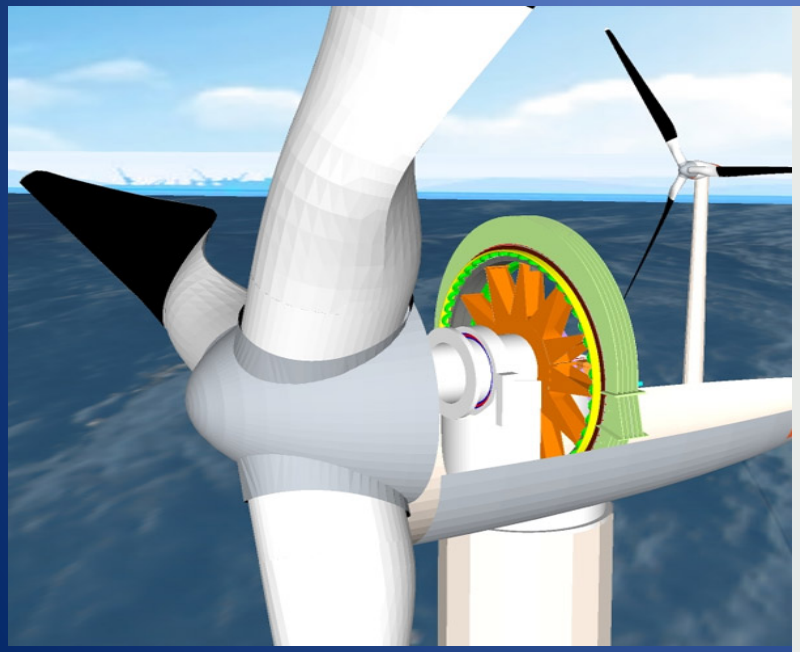
# CRYOGENIC COOLING SYSTEM

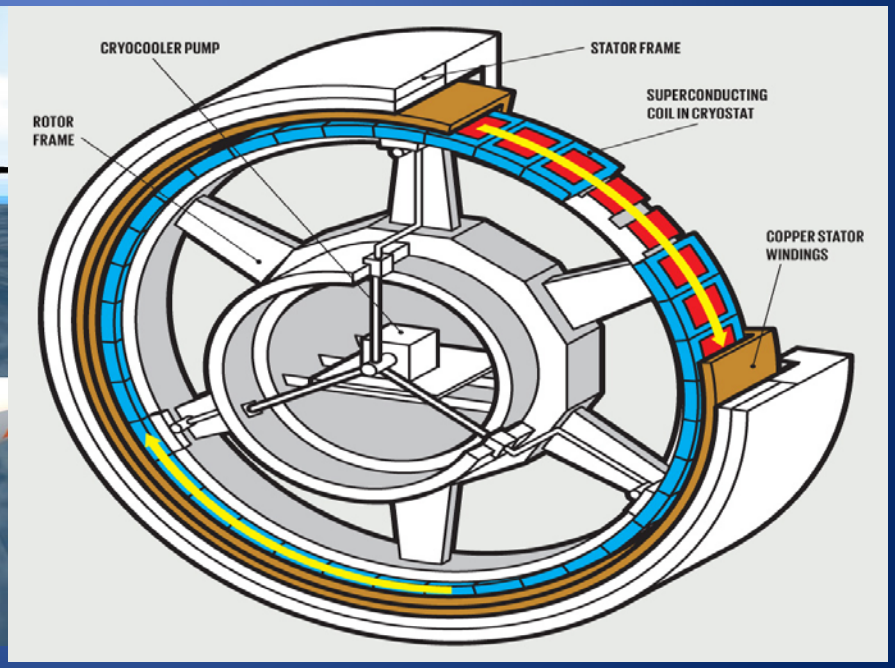
- One of the critical components of HTS devices is the cryogenic refrigeration system.
- Cryogenic systems used for HTS power applications are still relatively new and reliability is a concern because of the limited operating experience, especially in energy technology.
- Gifford-McMahon(G-M) cryocooler is the most popular type for cooling HTS field coils (50K, 1kW ).
- Main advantage of G-M type is the isolation of compressor from regenerator/displacer, which allows a modified air-conditioning compressor to be used.

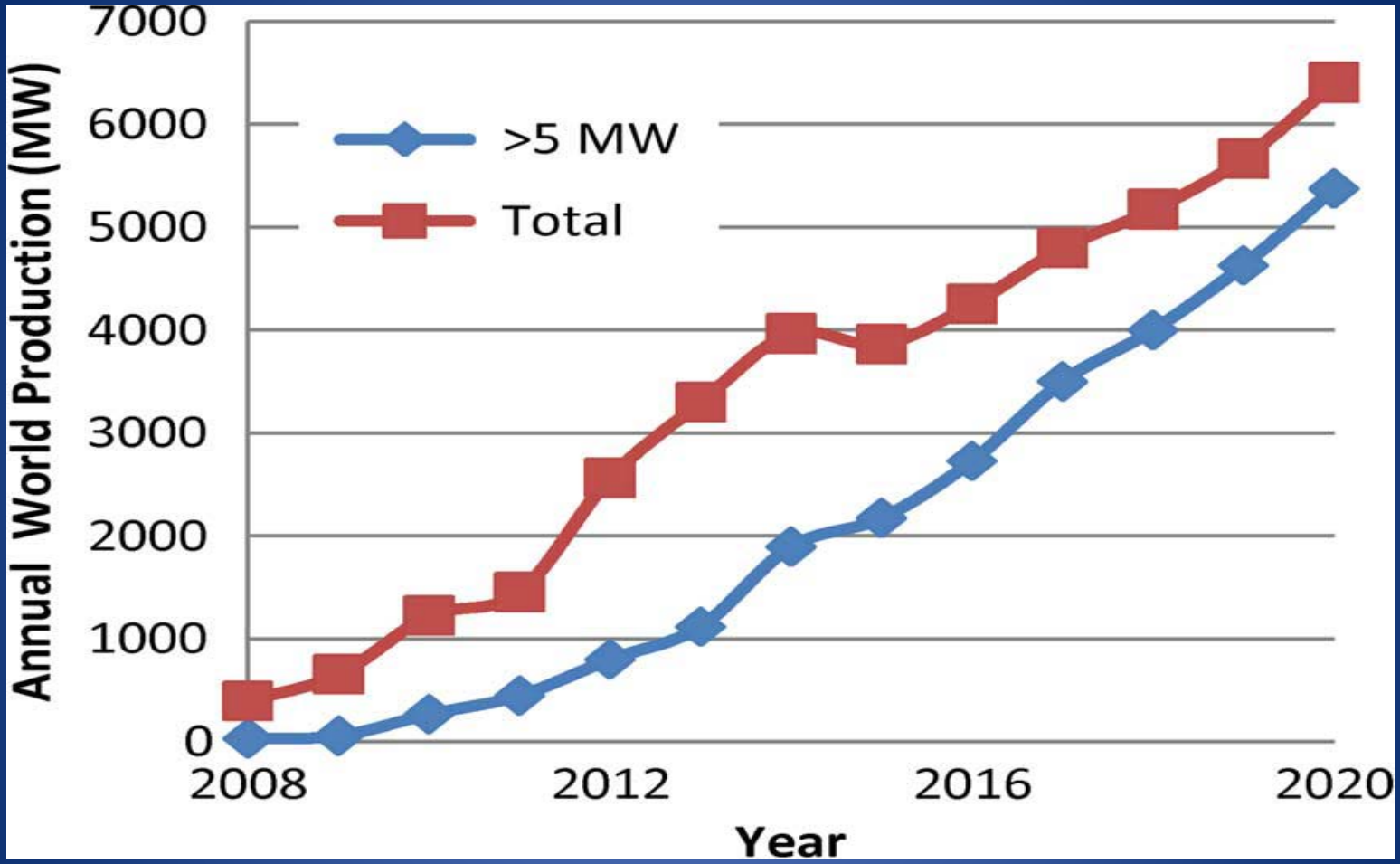
# CRYOCOOLER


Cryo-cooler
Cryostat
Thermal exchanger
Stator
Gas-Cooled Chamber
Neon Delivery Pipe
HTS rotor
HTS-PM Exciter
Neon Reservoir
Vacuum Space
HTS Rotor Coils

- SUPRAPOWER aims to provide an important breakthrough in offshore wind industrial solutions by designing an innovative, lightweight, robust and reliable 10 MW class offshore wind turbine based on a superconducting generator.
- This superconducting generator will be based on MgB2 wire to comply with the cost and reliability demanded by industry.
- MgB2 wire has already been used in coils for MRI commercial systems. Now, SUPRAPOWER will use it for wind-turbine generators.








Emerging market projection for offshore wind energy converters

# CRYOSTAT TOPOLOGIES

- Two possible designs of cryostat system the generator topology are shown below. In the former design, both the stator iron-core and SC coils work at the cryogenic environment, while the latter one only makes the SC coils in the cryogenic environment.
- The former scheme has simple structure compared with the latter one. However, the not small stator iron losses would result in higher cooling power and longer cool down time [13], while in the latter scheme, one cryostat contains one SC coil, therefore, although lots of cryostat are needed, but the total cooling power rating greatly decreases since the stator core is not located in the cryostat. As a result, the latter structure is selected for this FSCSG topology.

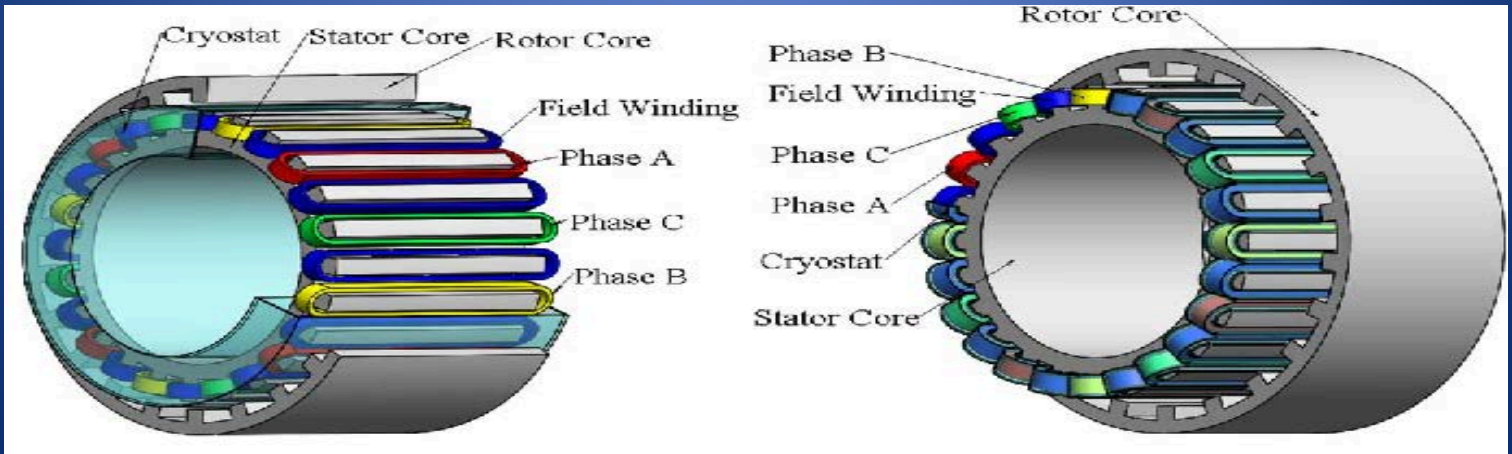



**Fig a – Both stator iron-core and sc coils in the cryogenic environment**

**Fig b – Only sc coils in the cryogenic environment**

Fig A: Siemens 4 MVA HTS generator

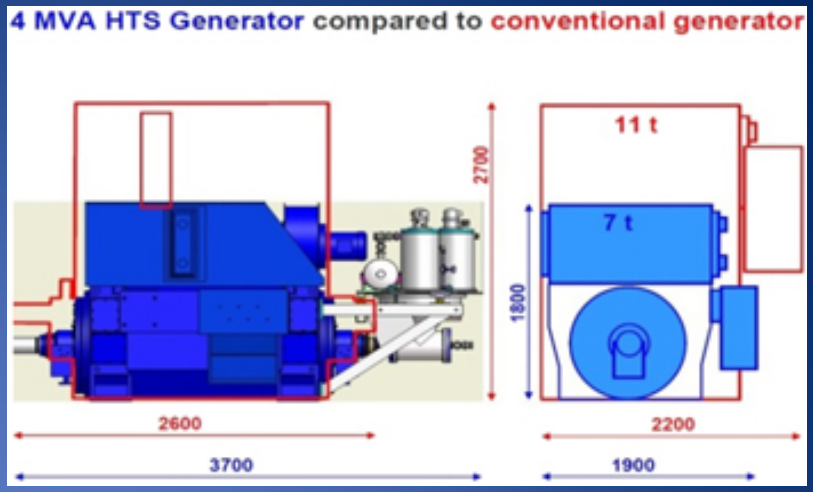
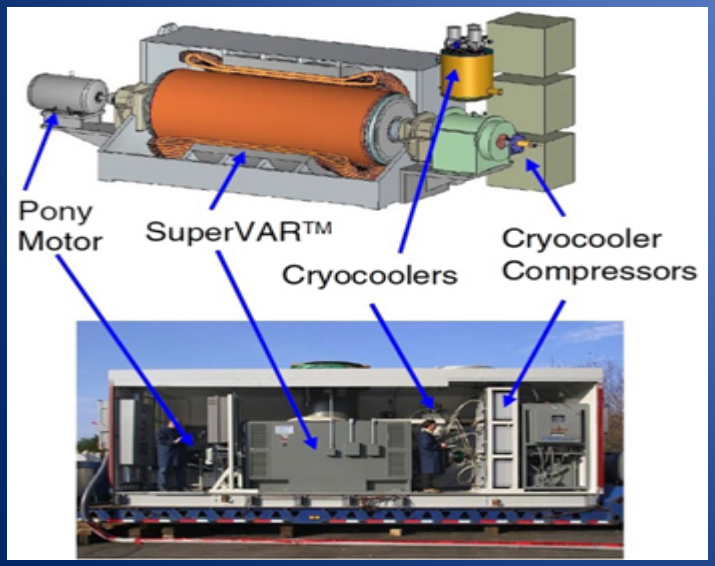



Fig B: Size and weight comparison to conventional generator

•The efficiency of the HTS generator was shown to be almost 2% highest (at 98.7%) than a conventional generator of the same rating.




American Superconductor (AMSC) has demonstrated an 8 MVA SuperVAR for TVA transmission system. The HTS SuperVAR has proven to be an economic option for providing reactive compensation to a power system and is the first commercial application of HTS technology.

# CONCLUSION

- Compared to conventional generators of similar power rating, HTS enables very compact generator units integrated with offshore wind turbines, with much reduced mass.
- Wind turbine generators that use permanent magnets, often neodymium–iron–boron, makes them heavy. Further, they require substantial quantities of rare earth metals which are expensive.
- Wind turbine generators could be made from High Tc superconducting field coils, located in annular cryo-stats offer significant savings in size and weight.
- Suitable cyro-refrigerators/long HTS tapes should be made available at competitive price to make these offshore superconducting turbo generators commercially viable.

# THANK YOU

# REFERNCES

The world's most powerful
Off Shore Wind Turbines
The world's most powerful Off Shore Wind Turbines.
The Offshore Generator (HTS) designed for Conventional Turbines.
Why HTC Generator

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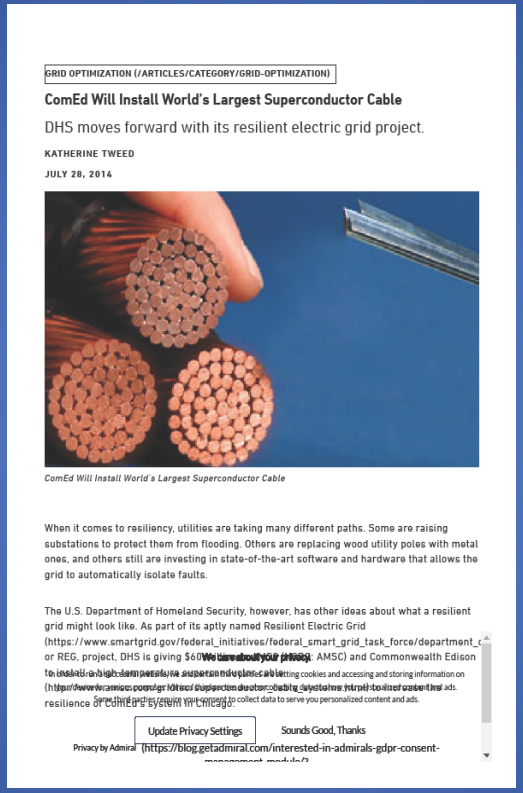
GRID OPTIMIZATION (/ARTICLES/CATEGORY/GRID-OPTIMIZATION)
ComEd Will Install World's Largest Superconductor Cable
DHS moves forward with its resilient electric grid project.
KATHERINE TWEED
JULY 28, 2014
ComEd Will Install World's Largest Superconductor Cable
When it comes to resiliency, utilities are taking many different paths. Some are raising substations to protect them from flooding. Others are replacing wood utility poles with metal ones, and others still are investing in state-of-the-art software and hardware that allows the grid to automatically isolate faults.
The U.S. Department of Homeland Security, however, has other ideas about what a resilient grid might look like. As part of its aptly named Resilient Electric Grid
Update Privacy Settings
Sounds Good, Thanks

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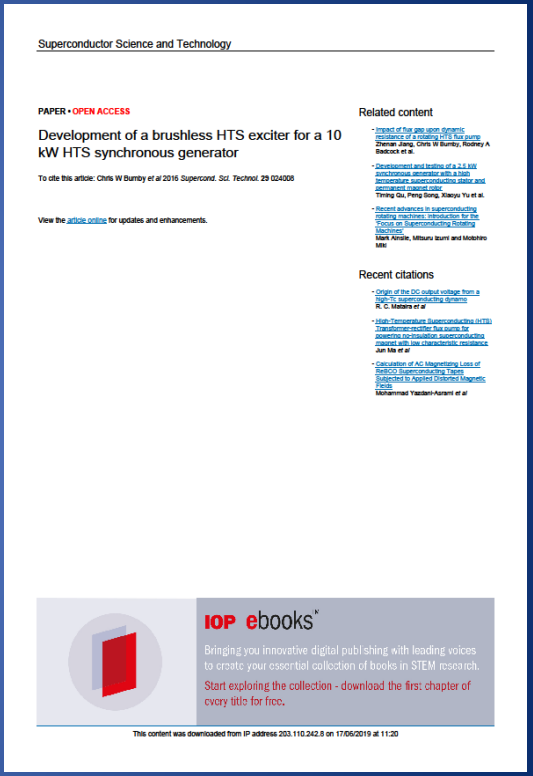
Superconductor Science and Technology
PAPER • OPEN ACCESS
Development of a brushless HTS exciter for a 10 kW HTS synchronous generator
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# REFERNCES

suprapower

Superconducting light generators for large offshore wind turbines

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SUPRAPOWER project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 308793

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Summary

SUPRAPOWER (SUPerconducting, Reliable, lightweight, And more POWERful offshore wind turbine) is an EU FP7 founded research project focused on a major innovation in offshore wind turbine technology by developing a new compact superconductor-based generator.

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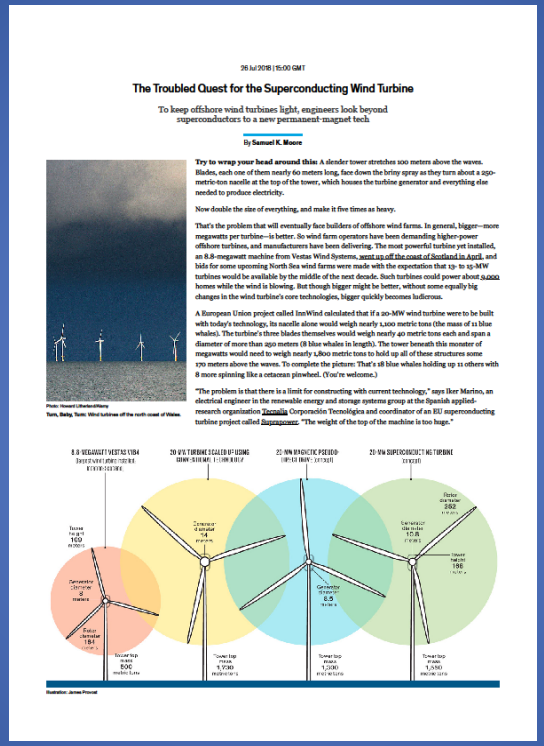

26 Jul 2018 | 15:00 GMT

The Troubled Quest for the Superconducting Wind Turbine

To keep offshore wind turbines light, engineers look beyond superconductors to a new permanent-magnet tech

By Samuel K. Moore

**Try to wrap your head around this:** A slender tower stretches 100 meters above the waves. Blades, each one of them nearly 60 meters long, face down the briny spray as they turn about a 250-metric-ton nacelle at the top of the tower, which houses the turbine generator and everything else needed to produce electricity.

Now double the size of everything, and make it five times as heavy.

That's the problem that will eventually face builders of offshore wind farms. In general, bigger—more megawatts per turbine—is better. So wind farm operators have been demanding higher-power offshore turbines, and manufacturers have been delivering. The most powerful turbine yet installed, an 8.8-megawatt machine from Vestas Wind Systems, went up off the coast of Scotland in April, and bids for some upcoming North Sea wind farms were made with the expectation that 10- to 15-MW turbines would be available by the middle of the next decade. Such turbines could power about 9,000 homes while the wind is blowing. But though bigger might be better, without some equally big changes in the wind turbine's core technologies, bigger quickly becomes ludicrous.

A European Union project called IncWind calculated that if a 10-MW wind turbine were to be built with today's technology, its nacelle alone would weigh nearly 1,000 metric tons (the mass of 11 blue whales). The turbine's three blades themselves would weigh nearly 40 metric tons each and span a diameter of more than 250 meters (8 blue whales in length). The tower beneath this monster of megawatts would need to weigh nearly 1,800 metric tons to hold up all of these structures some 170 meters above the waves. To complete the picture: That's 18 blue whales holding up 11 others with 8 more spinning like a cetacean pinwheel. (You're welcome.)

"The problem is that there is a limit for constructing with current technology," says Iker Marino, an electrical engineer in the renewable energy and storage systems group at the Spanish applied-research organization Tecnalia Corporación Tecnológica and coordinator of an EU superconducting turbine project called Superpower. "The weight of the top of the machine is too huge."

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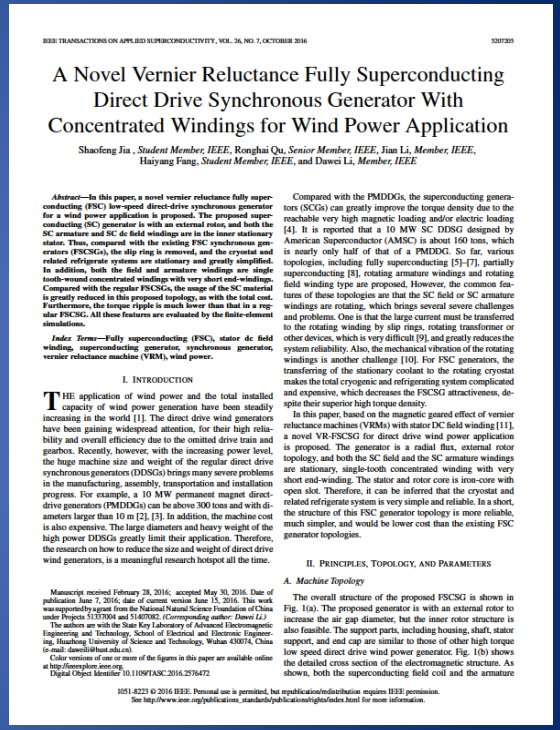

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 26, NO. 7, OCTOBER 2016 5207205

A Novel Vernier Reluctance Fully Superconducting Direct Drive Synchronous Generator With Concentrated Windings for Wind Power Application

Shaofeng Jia , *Student Member, IEEE*, Ronghai Qu, *Senior Member, IEEE*, Jian Li, *Member, IEEE*, Haiyang Fang, *Student Member, IEEE*, and Dawei Li, *Member, IEEE*

***Abstract*—In this paper, a novel vernier reluctance fully superconducting (FSC) low-speed direct-drive synchronous generator for a wind power application is proposed. The proposed superconducting (SC) generator is with an external rotor, and both the SC armature and SC dc field windings are in the inner stationary stator. Thus, compared with the existing FSC synchronous generators (FSCSGs), the slip ring is removed, and the cryostat and related refrigerate systems are stationary and greatly simplified. In addition, both the field and armature windings are single tooth-wound concentrated windings with very short end-windings. Compared with the regular FSCSGs, the usage of the SC material is greatly reduced in this proposed topology, as with the total cost. Furthermore, the torque ripple is much lower than that in a regular FSCSG. All these features are evaluated by the finite-element simulations.**

***Index Terms*—Fully superconducting (FSC), stator dc field winding, superconducting generator, synchronous generator, vernier reluctance machine (VRM), wind power.**

## I. Introduction

THE application of wind power and the total installed capacity of wind power generation have been steadily increasing in the world [1]. The direct drive wind generators have been gaining widespread attention, for their high reliability and overall efficiency due to the omitted drive train and gearbox. Recently, however, with the increasing power level, the huge machine size and weight of the regular direct drive synchronous generators (DDSGs) brings many severe problems in the manufacturing, assembly, transportation and installation progress. For example, a 10 MW permanent magnet direct-drive generators (PMDDGs) can be above 300 tons and with diameters larger than 10 m [2], [3]. In addition, the machine cost is also expensive. The large diameters and heavy weight of the high power DDSGs greatly limit their application. Therefore, the research on how to reduce the size and weight of direct drive wind generators, is a meaningful research hotspot all the time.

Compared with the PMDDGs, the superconducting generators (SCGs) can greatly improve the torque density due to the reachable very high magnetic loading and/or electric loading [4]. It is reported that a 10 MW SC DDSG designed by American Superconductor (AMSC) is about 160 tons, which is nearly only half of that of a PMDDG. So far, various topologies, including fully superconducting [5]–[7], partially superconducting [8], rotating armature windings and rotating field winding type are proposed, However, the common features of these topologies are that the SC field or SC armature windings are rotating, which brings several severe challenges and problems. One is that the large current must be transferred to the rotating winding by slip rings, rotating transformer or other devices, which is very difficult [9], and greatly reduces the system reliability. Also, the mechanical vibration of the rotating windings is another challenge [10]. For FSC generators, the transferring of the stationary coolant to the rotating cryostat makes the total cryogenic and refrigerating system complicated and expensive, which decreases the FSCSG attractiveness, despite their superior high torque density.

In this paper, based on the magnetic geared effect of vernier reluctance machines (VRMs) with stator DC field winding [11], a novel VR-FSCSG for direct drive wind power application is proposed. The generator is a radial flux, external rotor topology, and both the SC field and the SC armature windings are stationary, single-tooth concentrated winding with very short end-winding. The stator and rotor core is iron-core with open slot. Therefore, it can be inferred that the cryostat and related refrigerate system is very simple and reliable. In a short, the structure of this FSC generator topology is more reliable, much simpler, and would be lower cost than the existing FSC generator topologies.

## II. Principles, Topology, and Parameters

### A. Machine Topology

The overall structure of the proposed FSCSG is shown in Fig. 1(a). The proposed generator is with an external rotor to increase the air gap diameter, but the inner rotor structure is also feasible. The support parts, including housing, shaft, stator support, and end cap are similar to those of other high torque low speed direct drive wind power generator. Fig. 1(b) shows the detailed cross section of the electromagnetic structure. As shown, both the superconducting field coil and the armature

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